

## Pollination service to faba bean agroecosystem: quantifying and valuation using field experiment

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### ABSTRACT

In this study, pollination service in the faba bean agroecosystem was evaluated and valued with a field experiment. For this purpose, a factorial experiment based on a randomized complete blocks design with three replications was carried out in the research farm of Gorgan University of Agricultural Sciences and Natural Resources (Golestan province, Iran), during 2020-2021. The treatments of this experiment included cultivar as the first factor in four levels, including Feyz, Mahta, Barkat and Shadan and the second factor in two levels, including open-pollinated plants by insects and limitation of pollination by a cage. In this experiment, each plot included five planting rows with a distance between plants on each row of 15 cm, a planting depth of 5 cm and a distance between rows of 50 cm. Also, each plot had a size of 2×2.5 m and the distance between of plots was 75 cm. During the growing season, with the onset of warmer temperatures and insect activity in late March 2021, plots with limited open pollination are wholly trapped by the nets until the end of pollination. Simultaneously with the activity of insects in the field, samples of insects are collected using lattice nets. At the time of crop maturing, green yield and plant biomass were harvested. Finally, we quantified the value of pollination service by marketing price and alternative cost methods. In this study, we collected 13 pollinator species from the faba bean agroecosystem. The share of insects in the pollination of faba bean cultivars was obtained between 3.81 and 17.06 %. Results showed that the economic value of pollination in the faba bean agroecosystem was between 38,056,136 to 161,000,000 RIs.ha<sup>-1</sup>. Generally, the role of pollinating insects in new faba bean cultivars was more than in the old cultivars, especially, the cultivars such as Mahta that use more pollination service than other cultivars. It is necessary that faba bean growers promote and protect pollination service to enhance their economic benefits in agroecosystems.

### Highlights

- Faba bean pollination by 13 insect species boosts yield by 3.81-17.06% in Gorgan, Iran.
- Economic value of pollination ranges from 38M to 161M RIs/ha in faba bean fields.
- New cultivar Mahta relies most on insects (17.06%) vs. old cultivar Barkat (3.81%).
- Feyz and Barkat cultivars yield highest profit; Mahta benefits most from pollination.
- Study urges protecting pollinators for sustainable faba bean agroecosystem gains.

### 1. Introduction

Globally, agricultural ecosystems cover about 40% of the land (FAO, 2014), which are both providers and dependents on a variety of ecosystem services. They

provide critical ecological services such as food production, aesthetics, carbon sequestration, soil erosion control, pest control, soil health and water regulation (Sandhu et al., 2010). At the same time, agricultural

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ecosystems depend on services such as biodiversity, nutrients, soil structure and function, and water cycle (Power, 2010).

In recent decades, significant work has been done to determine the value of the functions, goods and services in the agroecosystems. Regulating services are concerned with the ability of natural and semi-natural ecosystems to regulate essential ecological processes and life support systems through bio-geochemical cycles and biosphere processes. Regulatory functions provide many services that have direct and indirect benefits to humans (Costanza et al., 1997).

The evaluation and quantification of various services and functions of agroecosystems are the most important ways to pay attention to these services and adopt appropriate strategies for their sustainability. For example, Andersson et al. (2014) investigated the effects of agricultural management and landscape heterogeneity on field bean pollination. Their results suggest that to maximize pollination success, it is important to improve field management and maintain natural habitats in agricultural landscapes.

In China, Zou et al. (2017) evaluated the relationships between landscape texture and pollinator communities. Their results showed that landscapes with small fields support an abundant but relatively species-poor bee community that provides pollination services to canola.

In Central Germany, Happe et al., (2018) investigated the effects of farming systems and scale agricultural landscapes on bee communities. Their results showed that organic system had the higher insect-pollinated richness. The value of insect pollination to yield of oilseed rape (*Brassica rapa*) in Bangladesh was estimated by Islam et al., (2022). They found that oilseed rape with visiting insects had a 30.8% greater yield compared to those where visitors were excluded. Also, they calculated the economic value of pollination at about \$US 26.92 million per annum.

Wild bees were sampled by Carrié et al. (2018) from 43 cereal fields in southwestern France, the surrounding proportion of permanent grasslands. They found that the mean slope of surrounding grasslands was the factor that most positively influenced bee richness, abundance and trait distribution in bee communities. They also found that the mean slope of surrounding grasslands had a better predictive power of bee community structure than the proportion of permanent grasslands. In another study, Cunningham and Feuvre, (2013) provided honeybee hives to 17 faba bean fields in South Australia, and they observed that bee activity and fruits per stem decreased with increasing distance from hives. They found an effect of distance from hives on mean yield.

Faba bean (*Vicia faba* L.) is one of the oldest crops that is mostly grown in Asian, African and Europe countries. This crop can be used in human and animal nutrition, which directly and indirectly provides the protein needs of humans (Majnoon Hosseini, 1996). Faba bean is a suitable crop for rotation with oilseeds and cereals due to the high amount of nitrogen bio-fixation and breaking the cycle of diseases. One of the regulating services provided by natural ecosystems to faba bean agroecosystem is insect

pollination. It is important for the productivity of grain in faba bean agroecosystems. Studies have confirmed that pollination by insects can improve plant yields. A study demonstrated that the yield benefits of additional pollination varied significantly among five faba bean cultivars, with some showing a yield increase of up to 37% under insect pollination, while others experienced a yield decrease of 51% when pollinated. This variability suggests that cultivar selection is crucial for optimizing yield through pollination (Bishop et al., 2020). Recent findings emphasize that while honeybees contribute to faba bean pollination, wild bumblebees are the most effective pollinators, accounting for approximately 70% of marketable yields in certain regions. This highlights the importance of maintaining diverse pollinator populations to maximize crop yields (Burns and Stanley, 2023). However, the importance of pollination as an ecosystem service depends on cultivar reproductive form, pollinator species and insect abundance.

In Iran, Golestan province is a suitable region for producing agricultural products. This province is one of the centers of faba bean production in the country, therefore paying attention to the pollination service can lead to development of sustainable production and more economic advantages for farmers and ecological advantages for the environment. The faba bean growers can protect the pollination service to enhance their economic benefits in agroecosystems. In this study, pollination service in a faba bean agroecosystem is evaluated, quantified and valued.

## 2. Materials and methods

### 2.1. Experimental site

During 2020-2021, a field experiment was conducted at the research farm of Gorgan University of Agricultural Sciences and Natural Resources, located in Gorgan county, Golestan province (northeast of Iran). Gorgan county is located in 54 degrees and 30 minutes' longitude of the east and 37 degrees and 45 minutes' latitude of the north, with the average height of 120 meters above sea level. In this county, there is usually a mild and semi-humid season and a relatively warm and semi-humid season. Gorgan has a semi-arid climate. The average annual temperature is 17.8 °C and the annual precipitation is approximately 584 mm.

### 2.2. Field operations

In this experiment, each plot included five planting rows with a distance between plants on each row of 15 cm, a planting depth of 5 cm and a distance between rows of 50 cm. Also, each plot had a size of 2×2.5 m and the distance between of plots was 75 cm. The amount of nitrogen was 10 kg/ha from nitrogen chemical fertilizer that was applied as a starter. Faba bean seeds were sown in late November 2020 and harvested early June 2021. During the growing season, the necessary care is carried out to control pests, diseases and weeds by non-chemical methods. We used physical methods to control pests and removed some of the infected leaves and branches. Additionally, we conducted two rounds of weeding to effectively control of weeds.

Also, supplementary irrigation was done two times during the growing season as a flooding method.

### 2.3. Quantification of pollination service

In this study, pollination regulation in the faba bean agroecosystem was quantified and valued by the performance of a field experiment. For this purpose, a factorial experiment was conducted as a randomized

complete blocks design with three replications at the research farm of Gorgan University of Agricultural Sciences and Natural Resources, during 2020-2021. The treatment composition of this experiment included: cultivars as the first factor in four types including, Feyz, Mahta, Barkat, and Shadan and pollination treatment as the second factor in two levels including, free pollination by insects and restriction of pollination by cages (Figure1).

<b>Plan</b>				
<b>Cultivars;</b> V1: Shadan, V2: Feyz, V3: Barkat, V4: Mahta				
<b>Pollination;</b> p1: Free, p2: Limited				
1	V1 <sub>p2</sub>	V3 <sub>p1</sub>	V4 <sub>p2</sub>	V2 <sub>p1</sub>
2	V2 <sub>p2</sub>	V1 <sub>p2</sub>	V4 <sub>p1</sub>	V3 <sub>p1</sub>
3	V4 <sub>p2</sub>	V1 <sub>p1</sub>	V2 <sub>p2</sub>	V3 <sub>p1</sub>



Figure 1. The design performance of field experiment, Gorgan, Iran.

Each cage had a size of 2×2.50×1 m from lattice nets type. At the time of crop ripening, grain yield, green biomass and Harvest Index (HI) were harvested from an area of one square meter of each plot. Finally, the marketing price and alternative cost methods were used to value this service. The marketing price method uses actual market prices for ecosystem services when they are available. One of the key concepts in this valuation process is alternative cost, which can be assessed through various cost-based methods. Alternative cost, often referred to as opportunity cost, represents the value of the best alternative forgone when a choice is made. In the context of ecosystem services, it helps quantify what society sacrifices when choosing one land use or resource management strategy over another (Pushpam, 2005; Selivanov and Hlaváčková, 2021). Also, statistical analysis of data performed using SAS software based on ANOVA and means compared based on LSD test at 5% probability level.

### 2.4. Insect collection

During the growing season, with the start of flowering and with the warming of the air and the start of insect activity, the limited plots by cages be wholly trapped by lattice nets until the end of the pollination stage. Simultaneously with the activity of insects in the field, samples were collected by a net trap. Surveys were

performed from 10:00 am to 12:00 pm, from late March to mid-April 2020. The samples were then collected, and all insects were transferred to jars containing 70% ethanol and glycerol. Insect samples were moved to the entomology laboratory of Gorgan University of Agricultural Sciences and Natural Resources, then, they were identified in terms of scientific names.

## 3. Results and discussion

### 3.1. Pollinator insects

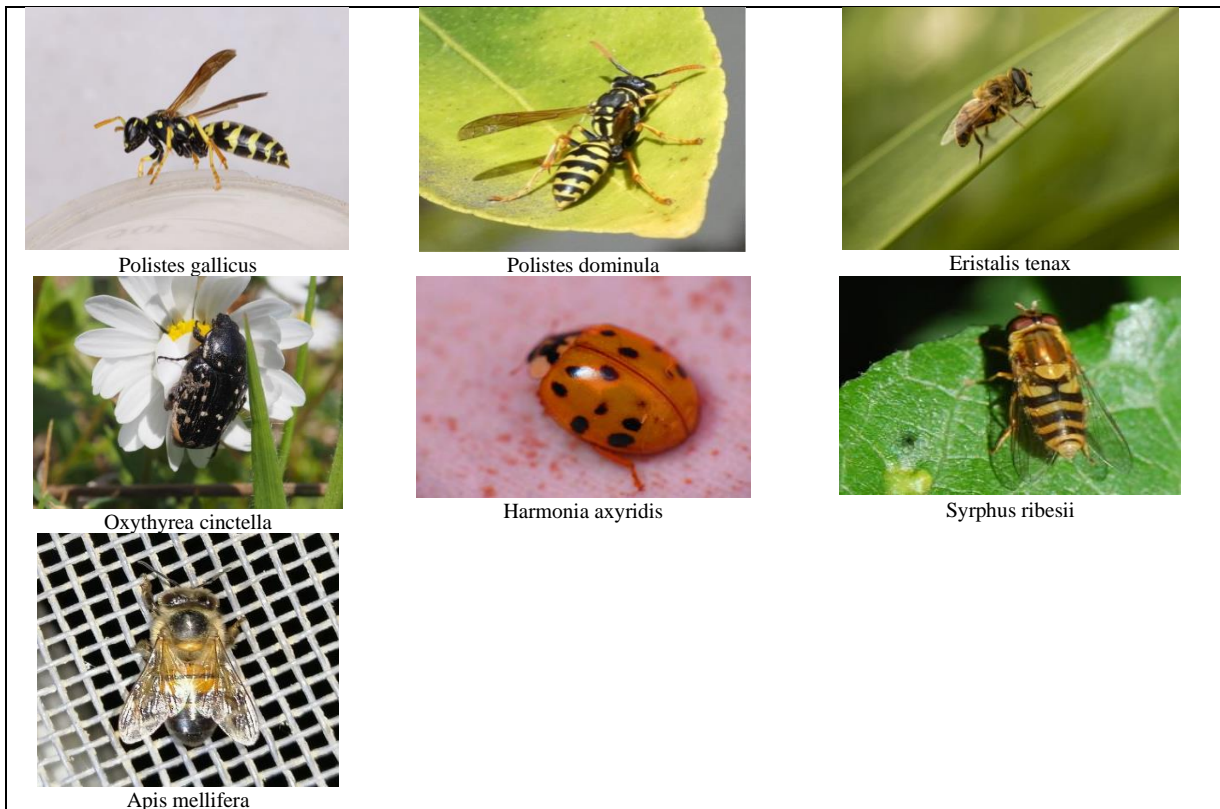
We collected 13 pollinator species from the faba bean agroecosystem. We found the faba bean plants were pollinated by *Polistes gallicus*, *Polistes dominulu*, *Spilostethus sp.*, *Eristalis tenax*, *Oxythyrea cinctella*, *Ichneumonidae*, *Harmonia axyridis*, *Syrphus ribesii*, *Pygopleurus sp.*, *Sphecodes sp.*, *Lasioglossum sp.*, *Anthophora sp.* and *Apis mellifica* in Gorgan (Table 1). Some of the pollinators shown in Figure 2. Before this research, Liu et al. (2020) reported that pollination efficiencies were high for species *Apis mellifera*, *Apis cerana*, *Eristalis tenax*, and *Tiphia vernalis* in common buckwheat and adult Syrphidae flies are of second importance after bees as the second most pollinating group in the insect category. In our study, Halictid bees (*Lasioglossum sp.*) had the most abundant (25.71%),

followed by European paper wasp (*Polistes dominula*) (20.0%), *Pygopleurus* sp (11.43%) and *Spilostethus* sp. (8.57%) (Table 1). Lundin (2023) found that honeybees provide 47% of the insect pollination services for faba bean, while short-tongued bumblebees contribute 40%,

long-tongued bumblebees account for 6%, and solitary bees make up 8% of the services. This indicates that both managed honeybees and wild bees, particularly short-tongued bumblebees, play a significant role in the pollination of faba beans in Sweden.

**Table 1. Scientific name, family name and frequency of pollinators in faba bean agroecosystem, Gorgan, Iran.**

	Scientific name	Family name	Frequency (%)
1	<i>Polistes gallicus</i>	Vespidae	2.85
2	<i>Polistes dominula</i>	Vespidae	20.00
3	<i>Spilostethus</i> sp.	Lygaeidae	8.57
4	<i>Eristalis tenax</i>	Syrphidae	2.85
5	<i>Oxythyrea cinctella</i>	Scarabaeidae	2.85
6	Ichneumonidae	Ichneumonidae	5.71
7	<i>Harmonia axyridis</i>	Coccinellidae	2.85
8	<i>Syrphus ribesii</i>	Syrphidae	5.71
9	<i>Pygopleurus</i> sp.	Glaphyridae	11.43
10	<i>Sphecodes</i> sp.	Halictidae	2.85
11	<i>Lasioglossum</i> sp.	Halictidae	25.71
12	<i>Anthophora</i> sp.	Apidae	5.71
13	<i>Apis mellifera</i>	Apidae	2.85



**Figure 2. Some pollinators in faba bean agroecosystem (Source: GBIF)**

The genus *Lasioglossum* in Halictidae is one of the largest genera of bees worldwide with an incredibly diverse array of behaviors. These bees are found worldwide, but are especially abundant in temperate regions. Halictidae are one of the six bee families in the order Hymenoptera. They are a very diverse group of metallic and non-metallic bees and certainly are more abundant than most bees except *Apis* species (Buckley et al., 2019). In Catalonia (Spain), Morrison et al., (2017) found a strong inverse relationship between wild bee abundance and surrounding landscape

diversity in cereal fields margins. For example, they reported that with decreasing landscape complexity in Catalonia, the proportion of Halictidae bees increased.

In this study, European paper wasp (*Polistes dominula*) had an abundance of about 20.0%. This insect is a eusocial paper wasp native to Mediterranean Europe. Individual records for this distribution could only be found for Europe and Iran. European paper wasp lives in a wide range of habitats within temperate climates, including woodland, shrubland, grassland agricultural and urban areas and this

insect builds nests using paper and saliva (Stout, 2013).

The findings regarding pollination services to faba beans have significant implications for both productivity and agroecosystem sustainability. Enhanced pollination, particularly through managed pollinators like honeybees, has been shown to increase yields by up to 49% compared to self-pollination conditions, highlighting the critical role of insect pollinators in maximizing crop output (Gasim, and Abdelmula, 2018).

### 3.2. Quantification of ES related to pollination

The results showed that the cultivar types had significantly different as green yield and biomass at the level of 1% probability (Table 2). The highest grain yield was related to Barkat cultivar, which was in the same statistically class as Feyz (Table 3). The share of insects in pollination of cultivars was between 3.81 and 17.06 % (Table 4). The highest share of the pollinating insects was related to Mahta cultivar. This cultivar from the medium seed group is suitable for cultivation in moderate and cold regions. The number of pods per plant for this cultivar is 25-40, with a protein content of about 28-31%, and it is resistant to diseases. Also, this cultivar is superior to other

faba bean cultivars and lines from the view of mechanized harvesting. Mahta is the first cultivar without tannins and dual-purpose faba beans in Iran and can be used in feeding livestock, poultry and aquatics (Sheikh et al., 2017c). The results showed that the role of pollinating insects in new faba bean cultivars such as Mahta was more than the old cultivar such as Barkat. Globally, there is growing confirmation that improved pollination practices can help support higher yield and reduced variability for a wide range of insect-pollinated plants (Cunningham and Feuvre, 2013). In this study, it determined that the highest Harvest Index (HI) was related to Barkat as an old cultivar, and the lowest of HI was obtained in Mahta cultivar (Table 3). Also, the share of pollination by insects was obtained by 14.51% in Shadan cultivar (Table 4). Shadan cultivar belongs to the medium grain group. It is resistant to *Cercospora* leaf spot (*Cercospora zonata*) disease and is suitable for mechanized harvesting. This cultivar has about 3.5-5.0 t/ha grain yield with 20-28 t/ha green yield, 25 pods per plant and 27-30% protein content. Shadan as a new cultivar is suitable for human consumption as cotyledon (Sheikh et al., 2017b).

**Table 2. Results of analysis of variance (mean square) of ecosystem services related to pollination by insects in a faba bean agroecosystem, Gorgan, Iran.**

Source of variables	Green yield (kg/m <sup>2</sup> )	Green biomass (kg/m <sup>2</sup> )	HI (%)	Economic profit (10 <sup>7</sup> Rls/ha) *
Block	ns	ns	ns	ns
Pollination (P)	ns	ns	ns	ns
Cultivar (C)	**	*	ns	**
C*P	ns	ns	ns	ns
CV (%)	17.28	14.70	6.48	17.27

ns: Non-significant. \*\* Significant at 1% probability level, \* Significant at 5% probability level

**Table 3. Results of mean comparison of ecosystem services related to pollination by insects in a faba bean agroecosystem, Gorgan, Iran.**

Treatment	Green yield (kg/m <sup>2</sup> )	Green biomass (kg/m <sup>2</sup> )	HI (%)	Economic profit (10 <sup>7</sup> Rls/ha) *
<b>Pollination</b>				
Free pollination	2.790a	4.622a	37.54a	97.6a
Limited pollination	2.739a	4.632a	36.89a	95.7b
<b>Cultivar</b>				
Shadan	2.622b	4.705a	35.84bc	91.7bc
Feyz	3.142ab	5.081a	36.89b	109.9a
Barkat	3.212a	4.917a	39.41a	101.2ab
Mahta	2.073c	3.804b	35.26c	72.5c

\*Rls: Rials. Means with same letters in each column don't have significant differences based on the LSD test at the 5% probability level .

**Table 4. Share and economic value of pollination in faba bean agroecosystem, Gorgan, Iran.**

Cultivar	Pollination percentage	Economic value of pollination (Rls/ha) *
Shadan	14.51	135,566,667
Feyz	13.64	161,000,000
Barkat	3.81	38,056,136
Mahta	17.06	135,333,333

Rls: Rials

### 3.3. Valuation of pollination service

Results showed that cultivars had significant difference in economic profit. The highest profit was obtained in Feyz and Barkat cultivars (Table 3). Also, results showed that the economic value of pollination in the faba bean agroecosystem was between 38,056,136 to 161,000,000 Rls/ha. Feyz and Barkat cultivars had the highest and lowest profits from insect pollination, respectively (Table 4). Feyz cultivar as a new cultivar from coarse grain faba bean, is suitable for regions with moderate and semi-moderate of Iran. The pod length of the cultivar is high with

6-9 seeds per pod, and 145 grams of 100-seeds weight (Sheikh et al., 2015a). In the study by Cunningham and Feuvre (2013), the share of pollination by insects in faba bean fields was estimated at 17%. Economically, their analysis indicated that the provision of hives was profitable for a wide range of realistic values for crop value and pollination cost. In the same direction, Islam et al., (2021) reported that the value of oilseed rape was \$US 87.5 million annum<sup>-1</sup>, of which the economic value of insect pollination was \$US 26.92 million annum<sup>-1</sup> in Bangladesh. The application of input-output models for economic valuation

provides valuable insights into the agricultural sector's dynamics in Iran. By focusing on enhancing agribusiness productivity and implementing sustainable practices like managed hives, Iran can bolster its agricultural economy while addressing critical challenges such as food security. To focus on the characteristics of cultivars that are relevant to pollination efficiency and economic valuation, it's essential to consider how different cultivars interact with pollinators and the resultant effects on plant production and quality. A study revealed significant variations in the yield benefits of additional pollination across five different faba bean cultivars. Some cultivars experienced yield increases of up to 37% with insect pollination, while others saw a decline of 51% when pollinated. This variability highlights the importance of cultivar selection for maximizing yield through effective pollination (Bishop et al., 2020).

#### 4. Conclusion

Our results showed that pollination by insects can improve yield of faba bean and the value of insect pollination in this crop depended on insect species, cultivar type and insect abundances. According to this, the share of insects in pollination was obtained between 3.81 and 17.06 percent. Also, cultivars had significant difference in economic profit, and the role of pollinating insects in new faba bean cultivars was more than in the old cultivars. The study on faba bean pollination highlights the significant role that insect pollinators play in enhancing crop yield, particularly emphasizing the cultivar Mahta, which exhibits a higher dependency on pollination services compared to others. This finding underscores the need for a more direct connection between these results and broader ecological and agricultural practices, particularly in relation to sustainability and biodiversity within agroecosystems. To enhance their economic benefits within the faba bean agroecosystem, it is essential for farmers to understand the crucial role of insects in pollination. By actively promoting and protecting these pollination services, growers can ensure a more productive and sustainable farming future. Taking steps to create a pollinator-friendly environment will not only boost yields but also contribute to the overall health of the ecosystem and protect of biodiversity.

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